ANALYSIS AND EVALUATION OF UNCERTAINTY FOR CONDUCTED AND RADIATED EMISSIONS TESTS

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ABSTRACT

Whenever an EMC measurement is made, there are numerous uncertainties in different parts of the measurement system and even in the EMC performance of the equipment under test (EUT) which is being measured. It is important to be able to estimate the overall uncertainty, in particular, the test setup and measurement equipment uncertainty. However, making repetitive measurements can reduce the measurement uncertainty, but often economics of time do not permit that. Therefore, a practical process, which is used to evaluate uncertainty in EMC measurement a, according to the principle of uncertainty and conditions in EMC measurement is presented. In this study, an efficient analysis of uncertainty for both radiated and conducted emissions tests is performed. The uncertainty of each contributor had been calculated and evaluating the reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement. This standard uncertainty is multiplied by the coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The result of calculating the uncertainty for both conducted and radiated emission tests showed that the overall uncertainty of the system is high and it must be lowered by reducing the expanded uncertainty for the dominant contributors for both tests. In addition, the result of applying the concept of CISPR uncertainty for both conducted and radiated emission tests showed that non-compliance is deemed to occur for both EUT of both tests. This is due to the result that the measured disturbances increased by ($U_{lab} - U_{CISPR}$), above the disturbance limit.

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CHAPTER I

INTRODUCTION

1.1 Background

In recent years, electro-magnetic compatibility (EMC) technology and technological development have become extremely vital study areas in the world because of need of companies of electronic industries around the world to meet worldwide EMC standards.

EMC testing is a process of taking measurements. Whenever we measure a quantity, the result is never exactly correct value: the value we report will inevitably differ from the true value by some amount, hopefully small. This applies whether we are measuring length, voltage, time or any other parameter, complex or simple. EMC measurements are no different in this respect. But the subject of measurement uncertainty in EMC tests is more complex than most because:

- The equipment that is being tested was not designed specifically for the test – there is no "EMC" connection port,
- The test method usually includes set-up factors that affect the measurement,
- The test equipment is itself complex and includes several separate but interconnected components,
- The quantities involved may be electromagnetic fields, varying in space, and may be transient or continuous [1].

At first glance, measurement uncertainty (MU) is a complex subject, however, with a little study it becomes more understandable and more easily understood. Most practicing engineers are familiar with tolerances and error and similar terms. In general, the concept of MU is not as well known. One of the reasons for this is that the theory and practice of measurement uncertainty has only been around about 20 years[2].

In general, no measurement or test is performed perfectly and the imperfections in the process will give rise to error in the result. Consequently, the result of a measurement is, at best, only an approximation to the true value of the measurand (Specific quantity subject to measurement) and is only complete when the measured value is accompanied by a statement of the uncertainty of that approximation [3]. In this project, a mathematical modal is developed for the evaluation of uncertainty in EMC measurement.

1.2 Problem Statements

The motivation for studying the subject of EMC is now discussed. This motivation results from the imposition of additional design objectives for electronic systems to be electromagnetically compatible with the EM environment itself [4].

When an electrical or electronic equipment (product, appliance, system, device, etc.) complies with the requirements of the specified electro-magnetic compatibility (EMC) compliance tests, a relevant question seems to be: 'How certain are we that this equipment will not participate in an EM interference (EM) problem?' In other words: 'Will the equipment comply with the requirements set by the actual EM environment in which that equipment has to function satisfactorily without introducing any intolerable EM disturbances affecting anything in that environment?' In particular because an EMI problem strongly depends on the coupling path between the actual location of an actual disturbance source (inside an actual equipment) and the actual location of an actual victim (inside another actual equipment), a clear actual compliance uncertainty will always result when the compliance tests do not cover all possible actual situations in which that equipment will or may be used [5].

The uncertainty is a quantitative indication of the quality of the result. It gives an answer to the question, how well does the result represent the value of the quantity being measured? It allows users of the result to assess its reliability, for example for the purposes of comparison of results from different sources or with reference values. Confidence in the comparability of results can help to reduce barriers to trade.

Often, a result is compared with a limiting value defined in a specification or regulation. In this case, knowledge of the uncertainty shows whether the result is well within the acceptable limits or only just makes it. Occasionally a result is so close to the limit that the risk associated with the possibility that the property that was measured may not fall within the limit, once the uncertainty has been allowed for, must be considered [6].

The estimation of the uncertainty of a measurement allows meaningful comparison of equivalent results from different laboratories or within the same laboratory, or comparison of the result with reference values given in specifications or standards. Availability of this information can allow the equivalence of results to be judged by the user and avoid unnecessary repetition of tests if differences are not significant [3].

We may be interested in uncertainty of measurement simply because we wish to make good quality measurements and to understand the results. However, there are other more particular reasons for thinking about measurement uncertainty. We may be making the measurements as part of a:

- ***calibration*** - where the uncertainty of measurement must be reported on the certificate
- ***test*** - where the uncertainty of measurement is needed to determine a pass or fail

- ***tolerance*** - where we need to know the uncertainty before we can decide whether the tolerance is met [7].

1.3 Objectives

The objectives of this project are as follows:

- To calculate and analyze the uncertainty of radiated and conducted emission tests related to EMC.

- To indicate the dominant factor affecting the measurement results of radiated and conducted emissions tests based on the uncertainty results over time.

- To study the cases of compliance and non-compliance for electronic devices based on the CISPR uncertainty.

1.4 Scopes

This project is primarily concerned with the scope of the project is to focus on analyzing and measurement the uncertainty of radiated and conducted emissions tests. The scopes of this project are:-

● Radiated and conducted Emissions Tests

The radiated and conducted emissions tests are one of the basic requirements for electromagnetic compatibility compliance of most electronic and electrical products. Everything from phones, service equipment and modern technological products go through this process. The purpose of these tests is to ensure that other users are protected from the emissions generated when the product is used in their neighborhood. All commercial products will be tested against the standards which are mostly based on CISPR tests

● **Frequency Range**

The frequency range for conducted commercial measurements is from 9 kHz to 30 MHz, depending upon the regulation. Radiated emissions testing looks for signals broadcast for the EUT through space. The frequency range for these measurements is between 30 MHz and 1 GHz and based upon the regulation, can go up to 6 GHz and higher. These higher test frequencies are based on the highest internal clock frequency of the EUT [2].

● **Software Used**

- Microsoft Excel is used to develop a mathematical model to calculate the uncertainty.

● **Experiment Laboratory**

The radiated and conducted emissions tests will be done in (a shielded rooms and anechoic-chambers). in the ***Center For Electromagnetic Compatibility, Universiti Tun Hussein Onn Malaysia***, ***Batu Pahat - Johor.***

● **Project Limitation**

This project is limited to the estimation of uncertainties of emission measurements. Specification limits are usually presented in $dB\mu V$ for conducted emission measurements, and in $dB\mu V/m$ for radiated emission measurements.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

From IS0 Guide to the expression of uncertainty in measurement, Uncertainty (of measurement) is: (i), a parameter, associated with the result of a measurement that characterize the dispersion of the values that could reasonably be attributed to the measurand; (ii), the spread of values about the measurement result within which the value of the measurand may be expected to be found; (iii), a measure of the possible error in the estimated value of the measurand as provided by the result of a measurement.

IS0 Guide to the expression of uncertainty in measurement makes the point that the real value of a measurable quantity can never be known exactly, but can only be estimated. This is because the deviation from ideal of the measurement instrumentation is also an known [8].

2.2 Technology Development

The ISO/IEC Guide 98-3 [14], is the "father" of all Measurement Uncertainty documents. It is commonly just called the Guide of Uncertainty Measurement "GUM". It was first released in 1993 and, then, corrected and reprinted in 1995. It changed the world of measurements and the associated errors of measurement instrumentation. The world's highest authority in metrology, CIPM (Comite International des Poids et Mesures) realized that there was a need to convene the world's experts on Measurement Uncertainty in order to arrive at a consensus position on the subject. In 1977, the CIPM requested the BIPM (Bureau International des Poids et Mesures) to communicate with the national metrology laboratories around the world and assess the situation. By early 1979, responses had been received from 21 laboratories and the great majority of the labs thought that something needed to be done. Specifically, the labs thought that "it was important to arrive at an internationally accepted procedure for expressing measurement uncertainty and for combining individual uncertainty components into a single total uncertainty." A working group was formed, developed a process, and released Recommendation INC-1 on Expression of Experimental Uncertainties in 1980. This Recommendation was approved by the CIPM in 1981 and reaffirmed by the same body in 1986. The ISO (International Organization for Standardization) was given the responsibility of developing a detailed Guide based on the 1980 Recommendation. The responsibility was assigned to ISO Technical Advisory Group on Metrology (TAG 4) which promptly established Working Group 3 comprised of experts nominated by BIPM, IEC (International Electro technical Commission), ISO, and OIML (International Organization of Metrology). This TAG labored throughout the 1980s and into the early 1990s to produce the "Guide to the Expression of Uncertainty in Measurement" in 1993. This guide was corrected and reprinted in 1995 and then eventually published as ISO/IEC Guide 98-3 in 2008 [2].

Since the spring of 1992, and particularly in the past five years, there has been a resurgence in the need for understanding and applying the basic principles of measurement uncertainty. In the past two years there has been significant international attention drawn to the need for estimating and applying measurement uncertainty, especially for those laboratories that are accredited to ISO/IEC 17025 on the competency of calibration and testing laboratories [9].

2.2.1 EMC and Measurement Uncertainty - LAB 34 and CISPR 16-4-2

Two of the more important publications in the area of Electromagnetic Compatibility (EMC) and Measurement Uncertainty (MU) are LAB 34 [12] and CISPR 16-4-2 [16]. EMC and Measurement Uncertainty are receiving more attention as other CISPR Product Family Standards begin to adopt MU. LAB 34 is "The Expression of Uncertainty in EMC Testing" and is published by the United Kingdom Accreditation Service (UKAS). CISPR 16-4-2 is published by the International Electro technical Commission (IEC) and is titled "Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods – Part 4-2: Uncertainties, Statistics, and Limit Modeling – Uncertainty in EMC Measurements."

Both Measurement Uncertainty documents are based on the International Standards Organization (ISO) Guide to the Expression of Uncertainty in Measurement (GUM), 1993, corrected and reprinted in 1995. This publication is the grandfather of all Measurement Uncertainty documentation and is often referred to, simply, as the "GUM." However, it should be noted that the "GUM" has been cancelled and replaced by "ISO/IEC Guide 98-3 – Uncertainty of Measurement – Guide to the Expression of Uncertainty of Measurement (GUM:1995)." The first edition of ISO/IEC Guide 98-3 was published in 2008. (Note – IEC is the International Electro technical Commission; a sister organization to the ISO).

When the "GUM" was first published in 1993 (after almost a 16-year development period), it introduced a new general perspective on errors, tolerances, and measurement variances. Many seminars and workshops occurred, after the initial release of the "GUM", to help engineers understand the new concepts of Measurement Uncertainty and specifically, Measurement Uncertainty and EMC. Within a year of the release of the GUM, the British had released an EMC Measurement Uncertainty document called NIS 81 –

"The Treatment of Uncertainty in EMC Measurements"; it was published by the National Measurement Accreditation Service (NAMAS) in May of 1994. This was a first attempt to address EMC and Measurement Uncertainty. NIS 81 had a number of mistakes in it and it was replaced by LAB 34; which was first released in August of 2002. CISPR 16-4-2 was spun-off from CISPR 16-4 (Uncertainty in EMC Measurements) in November of 2003. So, since 2003, there have been two fairly stable documents that have addressed MU and EMC.

This can be seen by reviewing Figure 1, the Table of Contents of both documents; LAB 34 and CISPR 16-4-2.

Table 2.1: Tables of Contents for LAB34 and CISPR 16-4-2

LAB 34	CISPR 16-4-2
1 – Introduction	Foreword, Introduction and Table Recapitulating Cross-References
2 – Concepts	1 - Scope
3 – Steps in Establishing an Uncertainty Budget	2 – Normative References
4 – Compliance with Specification	3 – Definitions and Symbols
5 – (Normative) References	4 – Measurement Instrumentation Uncertainty
6 - Acknowledgements	Annex A (informative) – Basis for Ucispr Values in Table 1
Appendix A – Examples of Typical Uncertainty Budgets	Bibliography
Appendix B - Calculation of kp	
Appendix C – Calculation of Uncertainty in Logarithmic or Linear Quantities	

It can be seen that both documents have an Introductory paragraph, a References paragraph, a General paragraph on Concepts and/or Scope, a paragraph on Measurement Uncertainty budgets, and Examples of Measurement Uncertainty. This article will be primarily devoted to comparing and contrasting some of the Measurement Uncertainty Examples.

2.2.1.1 Comparison of Conducted Emissions

In LAB 34, the conducted disturbance (conducted emission) from 9 kHz to 150 kHz standard uncertainties are shown in Figure 2. The standard uncertainties include the Receiver Reading, the Attenuation of the Artificial Mains Network (AMN)-Receiver combination, the AMN Voltage Division Factor, the Receiver Sine Wave, the Receiver Pulse Amplitude, the Noise Floor Proximity, the AMN Impedance, a Frequency Step Error, Mismatch (Receiver Voltage Reflection Coefficient and AMN + Cable), Measurement System Repeatability, and Repeatability of the Equipment Under Test (EUT). Table A.1 of CISPR 16-4-2 includes all these values except for Frequency Step Error, Measurement System Repeatability, and Repeatability of the EUT. However, since LAB 34 assigns values of zero to Frequency Step Error and Repeatability of the EUT, the only difference between the tables and their standard uncertainties is Measurement System Repeatability with a standard uncertainty of 0.5 dB. Subtracting that value from the Combined Standard Uncertainties for LAB 34 as shown in Figure 2, we arrive at a Combined Standard Uncertainty of 2.11 dB. Assuming a k = 2 coverage factor, we arrive at a value of 4.22 dB for the Expanded Measurement Uncertainty (EMU). Comparing that to CISPR 16-4-2, we see that “16-4-2” has a value of 3.97 dB for its Expanded Measurement Uncertainty; thus, we have a difference of 0.25 dB between the two documents.

Table 2.2: Conducted Disturbances – LAB 34 – 9 kHz to 150 kHz

Symbol	Source of Uncertainty	Value	Probability distribution	Divisor	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}	$U_i^4(y)$
R_I	Receiver Reading	0.05	rectangular	1.732	1	0.03	0.001	∞	0
L_C	Attenuation AMN-receiver	0.40	normal 2	2.000	1	0.20	0.040	∞	0
L_{AMN}	AMN Voltage division factor	0.20	normal 2	2.000	1	.010	0.010	∞	0
dV_{SW}	Receiver Sine Wave	1.00	rectangular	1.732	1	0.58	0.333	∞	0
dV_{PA}	Receiver Pulse Amplitude	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dV_{PR}	Receiver Pulse repetition	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dV_{NF}	Noise Floor Proximity	0.00	rectangular	1.732	1	0.00	0.000	∞	0
dZ	AMN Impedance	3.60	triangular	2.449	1	1.47	2.160	∞	0
F_{STEP}	Frequency step error	0.00	recatngular	1.732	1	0.00	0.000	∞	0
M	Mismatch Receiver VRC 0.15 AMN+Cable 0.65	-0.89	U-shaped - -	1.414	1	-0.63	0.397	∞	0 0 0
R_S	Measurement Systems Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9	0.007
R_{EUT}	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000		0
$u_c(F_S)$	Combined Standard Uncertainty		normal			2.17	4.691	>3000	0.007
$U(F_S)$	Expanded Uncertainty		normal k+	2.00		4.3		>3000	

Most of this difference seems to be from Attenuation of the AMN-receiver combination which is 0.4 dB in LAB 34 and only 0.1 dB in CISPR 16-4-2. A second reduced-factor in “16-4-2” is the AMN impedance; the standard uncertainty for that in “16-4-2” is 1.37 dB while in LAB 34 it is 1.47 dB.

Looking at the next higher frequency range for conducted emissions, 150 kHz to 30 MHz, as shown in A2 of LAB 34 and Table A.2 of CISPR 16-4-2, we see an Expanded Measurement Uncertainty (EMU) of 3.9 dB in LAB 34 and an Expanded Measurement

Uncertainty of 3.6 dB in CISPR 16-4-2. If we subtract the Measurement System Repeatability standard uncertainty from LAB 34, we arrive at an EMU of 3.7 dB thus leaving us with a difference between the two documents of only 0.1 dB for conducted emissions between 150 kHz and 30MHz.

2.2.1.2 Radiated Emissions

There are a number of radiated emissions (radiated disturbances) that could be reviewed depending on the antenna-to-EUT distance and the horizontal versus vertical polarization of the antenna. I chose a 3-meter antenna distance for this analysis with a vertical polarization of the log-periodic antenna and a frequency range of 300 – 1000 MHz.

As seen from Figure 3, the number of standard uncertainty factors has increased from the previous conducted emission examples. The list of standard uncertainty factors includes Receiver Indication, Receiver Sine Wave, Receiver Pulse Amplitude, Receiver Pulse Repetition, Noise Floor Proximity, Antenna Factor Calibration, Cable Loss, Antenna Directivity, Antenna Factor Height Dependence, Antenna Phase Center Variation, Antenna Factor Frequency Interpolation, Site Imperfections, Measurement Distance Variation, Antenna Balance, Cross Polarization, Frequency Step Error, Mismatch, Measurement System Repeatability, and Repeatability of EUT.

Table 2.3: Radiated Emissions, Vertical, 300 MHz to 1000 MHz, 3-meter distance

Symbol	Source of Uncertainty	Value	Probability distribution	**Divisor**	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}	$U_i^4(y)$
R_I	Receiver Indication	0.05	rectangular	1.732	1	0.03	0.001	∞	0
dV_{SW}	Receiver Since Wave	1.00	normal 2	2.000	1	0.50	0.250	∞	0
dV_{PA}	Receiver Pulse Amplitude	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dV_{PR}	Receiver Pulse repetition	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dV_{NF}	Noise Floor Proximity	0.50	normal 2	2.000	1	0.25	0.063	∞	0
A_F	Antenna Factor Calibration	1.00	normal 2	2.000	1	0.50	0.250	∞	0
C_L	Cable Loss	0.50	normal 2	2.000	1	0.25	0.063	∞	0
A_D	Antenna Directivity	3.00	rectangular	1.732	1	1.73	3.000	∞	0
A_H	Antenna Factor Height Dependence	0.50	rectangular	1.732	1	0.29	0.083	∞	0
A_P	Antenna Phase Centre Variation	1.00	rectangular	1.732	1	0.58	0.333	∞	0
A_I	Antenna Factor Frequency Interpolation	0.25	rectangular	1.732	1	0.14	0.021	∞	0
S_I	Site Imperfections	4.00	triangular	2.449	1	1.63	2.667	∞	0
D_V	Measurement Distance Variation	0.60	rectangular	1.732	1	0.35	0.120	∞	0
D_{BAL}	Antenna Balance	0.00	rectangular	1.732	1	0.00	0.000	∞	0
D_{Cross}	Cross Polarization	0.90	rectangular	1.732	1	0.52	0.270	∞	0
F_{step}	Frequency step error	0.00	rectangular	1.732	1	0.00	0.000	∞	0
M	Mismatch Receiver VRC 0.2 Antenna+Cable VRC 0.3	-0.54	U-shaped - -	1.414	1	-0.38	0.144	∞	0 0 0
R_S	Measurement of System Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9	0.0069
R_{EUT}	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000		0
$u_c(y)$	Combined Standard Uncertainty		normal			3.00	9.014	>11000	0.0069
U(y)	Expanded Uncertainty		normal k=	2.00		6.0		>11000	

LAB 34 has three elements in its table that are not in “16-4-2”; they are Frequency Step Error, Measurement System Repeatability, and Repeatability of the EUT. Both Frequency Step Error and Repeatability of the EUT are zero in LAB 34, they don’t contribute to the Combined Standard Uncertainty. However, Measurement System Repeatability is 0.5 in LAB 34; subtracting that from the Standard Uncertainty Table leaves us with an Expanded Measurement Uncertainty for 300 MHz to 1000 MHz of 5.90 dB. The equivalent number from “16-4-2” is 5.18 dB. It should be noted that the “16-4-2” table includes a factor for Table Height of 0.1 dB. If we subtract that from the “16-4-2” table, we still have a value of 5.18 dB (the factor is so small it contributes very little to the expanded measurement uncertainty). This is a difference of 0.72 dB between the two documents for vertical polarization.

The major difference maker between the two documents is antenna directivity: LAB 34 has a value of 3.0 dB while “16-4-2” has a factor of only 1.0 dB for that value. LAB 34 has an expanded measurement uncertainty (EMU) of 4.9 dB for Vertical Polarization at 10-meters from 300 MHz to 1000 MHz; if we subtract the Measurement System Repeatability factor; we have an EMU of 4.76 dB. CISPR 16-4-2 has an EMU of 5.05 dB for this same situation. Obviously, with a difference of only 0.29 dB, we have very similar numbers for 10-meter vertical radiated field strength.

For horizontal radiated emissions, with a biconical antenna, from 30 MHz to 300 MHz, LAB 34 has no examples. CISPR 16-4-2 has an EMU of 4.95 dB for 3-meters and 4.94 dB for 10-meters.

CISPR 16-4-2 actually covers the frequency range from 30 MHz to 200 MHz while LAB 34 covers the frequency range from 30 MHz to 300 MHz; both with biconical antennas. It should be noted that the examples in both LAB 34 and CISPR 16-4-2 use typical values in their examples; an EMC Lab must generate its own measurement uncertainty values from calibration certificates, equipment manuals, or from a series of measurements for a statistical analysis (Type A).

Table 2.4: Summary of Emission Measurement Uncertainty Values

Quantity	LAB 34 Expanded Measurement Emission Value	CISPR 16-4-2 Expanded Measurement Value	Difference
Conducted Emission – 9 kHz – 150 kHz	4.22 dB	3.97 dB	0.25 dB
Conducted Emission – 150 kHz – 30 MHz	3.70 dB	3.60 dB	0.10 dB
Radiated Emission – 3-meters – Vertical – 30 MHz – 300 MHz	5.32 dB	5.06 dB	0.26 dB
Radiated Emission – 3-meters – Horizontal – 30 MHz -300 MHz	5.32 dB	4.95 dB	0.37 dB
Radiated Emissions – 3-meters – Vertical - 300 – 1000 MHz	5.9 dB	5.18 dB	0.72 dB
Radiated Emissions – 3-meters – Horizontal - 300 – 1000 MHz	No data	4.95 dB	N/A
Radiated Emission – 10-meters – Vertical – 30 MHz – 300 MHz	5.32 dB	5.04 dB	0.28 dB
Radiated Emission – 10-meters – Horizontal – 30 MHz – 300 MHz	No data	4.94 dB	N/A
Radiated Emissions – 10-meters – Vertical - 300 – 1000 MHz	4.76 dB	5.05 dB	0.29 dB
Radiated Emissions – 10 meters – Horizontal - 300 -1000 MHz	5.32 dB	4.95 dB	0.37 dB

It should be noted that in both LAB 34 and CISPR 16-4-2 documents a typical values in their examples are used; an EMC Lab must generate its own measurement uncertainty values from calibration certificates, equipment manuals, or from a series of measurements for a statistical analysis (Type A) [10].

2.2.1.3 Summary

It can be seen that there is a close correlation between the two EMC Measurement Uncertainty documents discussed in this project. Both LAB 34 and CISPR 16-4-2 can be used by EMC Labs as reference documents for their lab operations, lab measurement uncertainty calculations, and for accreditation purposes. As more CISPR, regional, and national standards adopt Measurement Uncertainty criteria, the two subject documents will become increasingly important for an EMC Lab.

2.3 The Uncertainty Measurement Theory

2.3.1 Basic Concepts

EMC standards include specification of what to be measured-the "Measurand"-and define a method for measuring it. For instance, in the conducted emissions test, this is an RF voltage measured by a test receiver connected to the terminals of a LISN. The process of measurement is imperfect and errors creep into the result. As a consequence, the result of a measurement only approximates to the true value of the measurand and is only complete when it carries a statement of the uncertainty of that approximation. In general, a source of error may be either random or systematic; uncertainty arises directly from the random effects, and from the systematic effects when these are imperfectly corrected or not corrected.

Random effects – for instance, noise on a DC voltage – affect the measured value. The random errors cannot be eliminated but increasing the number of observations and deriving a mean value may reduce the uncertainty due to their effect.

Systematic errors arise when a given quantity, which remains unchanged when a measurement is repeated under constant conditions, influences the result such as a calibration error. A systematic error introduces an offset between the true value of the measurand and the mean measured value. It may be possible to reduce such effects by applying a correction factor to the data, if the expected error is constant and known. If this is not done, then the full error must be included in the uncertainty budget.

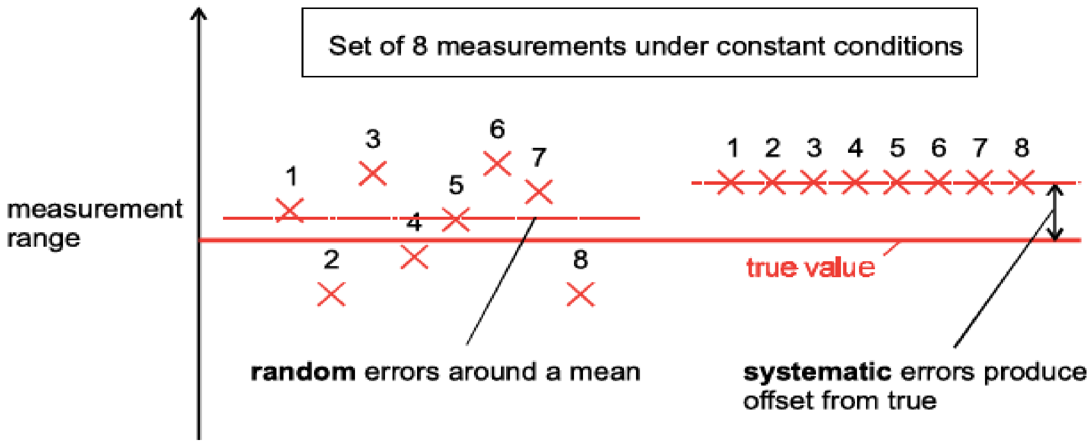

Figure 2.1: Random and Systematic Effects

An uncertainty budget lists the likely error sources and estimates individually their limits of uncertainty and probability distribution. To establish this list we need a reasonable degree of familiarity with the test method and the test instrumentation. When creating the list, it is better to be inclusive rather than exclusive – if a particular contribution turns out to be negligible, it is still better to acknowledge its presence and include it at a low or zero value than to ignore a contribution that may turn out to have greater significance than at first thought. Once we have analysed each component, the individual components are summed to produce the final result for the measurement [1].

Expressing uncertainty of measurement

Since there is always a margin of doubt about any measurement, we need to ask 'How big is the margin?' and 'How bad is the doubt?' Thus, two numbers are really needed in order to quantify an uncertainty. One is the width of the margin, or interval. The other is a confidence level, and states how sure we are that the 'true value' is within that margin.

Error versus uncertainty

It is important not to confuse the terms 'error' and 'uncertainty'.

Error is the difference between the measured value and the 'true value' of the thing being measured.

Uncertainty is a quantification of the doubt about the measurement result.

Whenever possible we try to correct for any known errors: for example, by applying corrections from calibration certificates. But any error whose value we do not know is a source of uncertainty

2.3.2 Sources of uncertainty

This section discusses how measurement uncertainties arise.

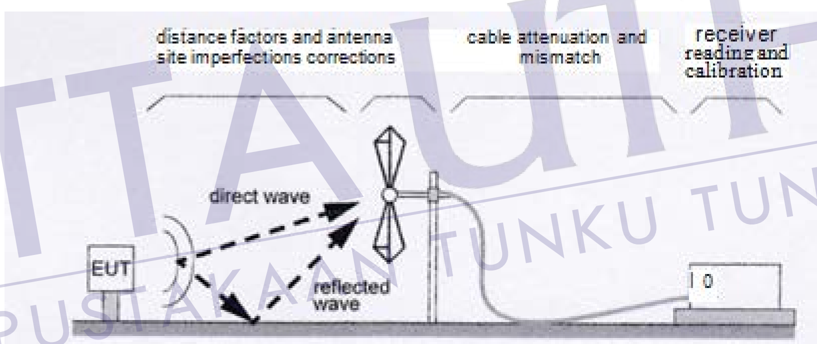

Figure 2.2: Sources of errors in radiated emission test

2.3.2.1 Instrument and cable errors:

Modern self-calibration test equipment can hold the uncertainty of measurement at the instrument input to within ±1dB. To fully account for the receiver errors, its pulse amplitude response, variation with pulse repetition rate, sine wave voltage accuracy, noise floor and reading resolution should all be considered. Input attenuator, frequency response, filter bandwidth and reference level parameters all drift with temperature and time, and can account for a cumulative error of up to 5dB at the input even of high quality instrumentation. To overcome this a calibrating function is provided. When this is invoked, absolute errors, switching errors and linearity are measured using an in-built calibration generator and a calibration factor is computed which then corrects the measured and displayed levels. It is left up to the operator when to select calibration, and this should normally be done before each measurement sweep. Do not invoke it until the instrument has warmed up- typically 30 minutes to an hour-or calibration will be performed on a “moving target”. A good habit is to switch the instruments on first thing in the morning and calibration them just before use.

The attenuation introduced by the cable to the input of the measuring instrument can be characterized over frequency and for good quality cable is constant and low, although long cables subject to large temperature swings can cause some variations. Uncertainty from this source should be accounted for but is normally not a major contributor. The connector can introduce unexpected frequency-dependent losses; the conventional BNC connector is particularly poor in this respect, and you should perform all measurements whose accuracy is critical with cables terminated in N-type connectors, properly tightened (and not cross-threaded) against the mating socket.

2.3.2.2 Mismatch uncertainty:

When the cable impedance, nominally 50Ω, is coupled to an impedance that is other than a resistive 50Ω at either end it is said to be mismatched. A mismatch termination will result in reflected signals and the creation of standing waves on the cable. Both the measuring instrument input and the antenna will suffer from a degree of mismatch which varies with frequency and specified as a Voltage Standing Wave Ratio (VSWR). If either the source or the load end of the cable is perfectly matched then no errors are introduced, but otherwise a mismatch error is created. Part of this is accounted for when the measuring instrument or antenna is calibrated. But calibration cannot eliminate the error introduced by the phase difference along the cable between source and load, and this leaves an uncertainty component whose limits are given by:

$$uncertainty = 20log_{10}(1 + \Gamma_l . \Gamma_s) \tag{2.1}$$

Where Γ_l and Γ_s are the source and load reflection coefficients.

As an example, an input VSWR of 1.5:1 and an antenna VSWR of 4:1 gives a mismatch uncertainty of ±1dB. The biconical in particular can have a VSWR exceeding 15:1 at the extreme low frequency end of its range. When the best accuracy is needed, minimize the mismatch error by including an attenuator pad of 6 or 10dB in series with one or bothe ends of the cable, at the expense of measurement sensitivity.

2.3.2.3 Conducted test factors:

Mains conducted emission tests use a LISN/AMN. Uncertainties attributed to this method include the quality of grounding of the LISN to the ground plane, the variations in distance around the EUT, and inaccuracies in the LISN parameters. Although a LISN theoretically has an attenuation of nearly 0dB across most of the frequency range, in practice this can't be assumed particularly at the frequency extremes and you should include a voltage division factor derived from the network's calibration certificate. In some designs, the attenuation at extremes of the frequency range can reach several dB. Mismatch errors, and errors in the impedance specification, should also be considered.

Other conducted tests use a telecom line ISN instead of a LISN, or use a current probe to measure common mode current. An ISN will have the same contributions as LISN with the addition of possible errors in the LCL. A current probe with the cable under test, and termination of the cable under test, as well as calibration of the probe factor.

2.3.2.4 Antenna calibration:

One method of calibrating an antenna is against a reference standard antenna, normally a tuned dipole on an open area test site. This introduces its own uncertainty, due to the imperfections both of the test site and of the standard antenna ±0.5dB is now achievable into the values of the antenna factors that are offered as calibration data. An alternative method of calibration known as the Standard Site Method uses three antennas and eliminates errors due to the standard antenna, but still depends on a high quality dite.

Further, the physical conditions of each measurement, particularly the proximity of conductors such as the antenna cable, can affect the antenna calibration. These factors are worst at the low frequency end of the biconical's range, and are exaggerated by antennas that that exhibit poor balance. When the antenna is in vertical polarization and close to the ground plane, any antenna imbalance interact with the cable and distorts its response. Also, proximity to the ground plane in horizontal polarization can affect the antenna's source impedance and hence its antenna factor. Varying the antenna height above the ground plane can introduce a height-related uncertainty in antenna calibration of up to 2dB.

These problems are less for the log periodic at UHF because nearby objects are normally out of the antenna's near field and do not affect its performance, and the directivity of the log periodic reduces the amplitude of off-axis signals. On the other hand the smaller wavelengths mean that minor physical damage, such as a bent element, has a proportionally greater effect. Also the phase centre (the location of the active part of the antenna) changes with frequency, introducing a distance error, and since at the extreme of the height scan the EUT is not on the boresight of the antenna its directivity introduces another error. Both of these effects are greatest at 3m distance.

An overall uncertainty of ±4dB to allow for antenna-related variations is not unreasonable, although this can be improved with care.

The difficulties involved in defining an acceptable and universal calibration method for antennas that will be used for emissions testing led to the formation of CISPR/A working group to draft such a method. It has standardized on a free-space antenna factor determined by a fixed-height 3-antenna method on a validated calibration test site. The method is fully described in CISPR 16-1-5.

2.3.2.5 Reflections and site imperfections:

The antenna measures not only the direct signal from the EUT but also any signals that are reflected from conducting objects such as the ground plane and the antenna cable. The field vectors from each these contributions add at the antenna. This can result in an enhancement approaching +6dB or a null which could exceed -20dB. Reflections from the ground plane cannot be avoided but nulls can be eliminated by varying the relative distances of the direct and reflected paths. Other objects further away than the defined CISPR ellipse will also add their reflection contribution, which will normally be small (typically less than 1dB) because of their distance and presumed low reflectivity.

This contribution may become significant if the objectives are mobile, for instance people and cars, or if the reflectivity varies, for example trees or building surfaces after a fall of rain. They are also more significant with vertical polarization, since the majority of reflecting objects are predominantly vertically polarized. With respect to the site attenuation criterion of ±4dB, CISPR 16-4-2 states: “measurement uncertainty associated with CISPR 16-1 site attenuation measurement method is usually large, and dominated by the two antenna factor uncertainties. Therefore a site which meets the 4dB tolerance is unlikely to have imperfections sufficient to cause errors of 4dB in disturbance measurements. In recognition of this, a triangular probability distribution is assumed for the correction”.

2.3.2.6 Antenna Cable:

With a poorly balanced antenna, the antenna cable is a primary source of error. By its nature it is a reflector of variable and relatively uncontrolled geometry close to the antenna. There is also a problem caused by secondary reception of common mode currents flowing on the sheath of the cable. Both of these factors are worse with vertical polarization, since the cable invariably hangs down behind the antenna in the vertical plane. They can both be minimized by chocking the outside of the cable with ferrite sleeve suppress spaced along it, or by using ferrite loaded RF cable. If this is not done, measurement errors of up to 5dB can be experienced due to cable movement with vertical polarization. However, modern antennas with good balance, which is related to balun design, will minimize this problem.

2.3.3 ISO Guide Approach

According to the basic resource documents for measurement uncertainty, a statement of expanded uncertainty (U) shall accompany every measurement. The expanded uncertainty has a specified probability of containing the true value, *i.e.*, a probability of coverage (sometimes called a "confidence interval''). If the true value is Y, the measured value is y, and the uncertainty of the measurement is U, the $Y = y \pm U$ n. That is, Y lies within the range from $y - U$ to $y + U$ [9].

There are two types of evaluations of uncertainty, Type A contributions (random effects) and Type B contributions (systematic effects). Type A evaluation is done by calculation from a series of repeated observations, using statistical methods, and resulting in a probability distribution that is assumed to be normal. A pre-determination of the uncertainty due to random contributions is given by the standard deviation $S(q_k)$ of a series of n such measurements q_k :

$$S(q_k) = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}(q_k - Q)^2} \tag{2.2}$$

Where Q is the mean value of the n measurements. This value of $s(q_k)$ is used directly for the uncertainty due to random contributions, excluding the effects of the EUT, when only one measurement is made on the EUT. But if the result of the measurement is close to the limit, it is advisable to perform several measurements on the EUT itself, at least at those frequencies that are critical. In this case, the uncertainty is reduced proportional to the square root of the number of measurements [1]:

$$s(Q) = \frac{s(q_k)}{\sqrt{n}} \tag{2.3}$$

Type B evaluations include all other methods. Type B evaluations may be based on:

• Previous measurement data;

• Data provided in calibration and other certificates (without descriptive statistics);

• Manufacturer's specifications, e.g., tolerances;

• Experience with, or general knowledge of, the properties of instruments and materials; and,

• Uncertainties assigned to reference data taken from handbooks [9].

2.3.4 Summation of contributions

Type A contributions are already in the form of a "standard uncertainty" and need no further treatment. Type B contributions need a further step before they can be summed. This involves determining the appropriate probability distribution for each contribution. For EMC tests, the relevant probability distributions are:

- **Normal:** uncertainties derived from multiple contributions, for example calibration uncertainties with a statement of confidence.
- **Rectangular:** equal probability of the true value lying anywhere between two limits, for example manufacturers' specifications.
- **U-shaped:** applicable to mismatch uncertainty, where the probability of the true value being close to the measured value is low.
- **Triangular**: the probability of the true value lying at a point between two limits increases uniformly from zero at the extremities to the maximum at the centre

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